



---

Year: 2018

---

## **Retention Load of Telescopic Crowns with Different Taper Angles between Cobalt-Chromium and Polyetheretherketone Made with Three Different Manufacturing Processes Examined by Pull-Off Test**

Wagner, Christina ; Stock, Veronika ; Merk, Susanne ; Schmidlin, Patrick R ; Roos, Malgorzata ;  
Eichberger, Marlis ; Stawarczyk, Bogna

**Abstract:** **PURPOSE** To investigate the retention loads of differently fabricated secondary telescopic polyetheretherketone (PEEK) crowns on cobalt-chromium primary crowns with different tapers. **MATERIALS AND METHODS** Cobalt-chromium primary crowns with 0°, 1°, and 2° tapers were constructed, milled, and sintered. Corresponding secondary crowns were fabricated by milling, pressing from pellets, and pressing from granules. For these nine test groups, the pull-off tests of each crown combination were performed 20 times, and the retention loads were measured (Zwick 1445, 50 mm/min). Data were analyzed using linear regression, covariance analysis, mixed models, Kruskal-Wallis, and Mann-Whitney U-test, together with the Benferroni-Holm correction. **RESULTS** The mixed models covariance analysis reinforced stable retention load values ( $p = 0.162$ ) for each single test sequence. There was no interaction between the groups and the separation cycles ( $p = 0.179$ ). Milled secondary crowns with 0° showed the lowest mean retention load values compared to all tested groups ( $p = 0.003$ ) followed by those pressed from pellets with 1°. Regarding the different tapers, no effect of manufacturing method on the results was observed within 1° and 2° groups ( $p = 0.540$ ;  $p = 0.052$ ); however, among the 0° groups, the milled ones showed significantly the lowest retention load values ( $p = 0.002$ ). Among the manufacturing methods, both pressed groups showed no impact of taper on the retention load values ( $p > 0.324$  and  $p > 0.123$ , respectively), whereas among the milled secondary crowns, the 0° taper showed significantly lower retention load values than the 1° and 2° taper ( $p < 0.002$ ). **CONCLUSION** Based on these results, telescopic crowns made of PEEK seem to show stable retention load values for each test sequence; however, data with thermo-mechanical aging are still required. In addition, further developments in CAD/CAM manufacturing of PEEK materials for telescopic crowns are warranted, especially for 0°.

DOI: <https://doi.org/10.1111/jopr.12482>

Posted at the Zurich Open Repository and Archive, University of Zurich

ZORA URL: <https://doi.org/10.5167/uzh-132884>

Journal Article

Accepted Version

Originally published at:

Wagner, Christina; Stock, Veronika; Merk, Susanne; Schmidlin, Patrick R; Roos, Malgorzata; Eichberger, Marlis; Stawarczyk, Bogna (2018). Retention Load of Telescopic Crowns with Different Taper Angles between Cobalt-Chromium and Polyetheretherketone Made with Three Different Manufacturing Processes Examined by Pull-Off Test. *Journal of Prosthodontics*, 27(2):162-168.

DOI: <https://doi.org/10.1111/jopr.12482>

**Journal:** Journal of Prosthodontics

**1. Full title of manuscript**

**Retention load of telescopic crowns with different taper angles between cobalt-chromium and polyetheretherketone made of three different manufacturing processes examined by pull-off test**

**2. Authors' full names**

med. dent. Christina Wagner<sup>a</sup>, med. dent. Veronika Stock<sup>a</sup>, med. dent. Susanne Merk<sup>a</sup>, Prof. Dr. med. dent. Patrick R. Schmidlin<sup>b</sup>, Malgorzata Roos PhD<sup>c</sup>, Marlis Eichberger<sup>a</sup>, Dr. rer. biol. hum. Dipl.-Ing. (FH) Bogna Stawarczyk, MSc<sup>a</sup>

**3. Authors' affiliations**

<sup>a</sup>Department of Prosthodontics, Dental School, Ludwig-Maximilians-University Munich, Goethestrasse 70, 80336 Munich, Germany

<sup>b</sup>Clinic of Preventive Dentistry, Periodontology and Cariology, Center of Dental Medicine, University of Zurich, Switzerland

<sup>c</sup>Division of Biostatistics, Epidemiology Biostatistics and Prevention Institute, University of Zurich, Hirschengraben 84, 8001 Zurich, Switzerland

**4. Running title: retention loads of polyetheretherketone telescopic crowns**

**5. Corresponding Author details:**

Dr. rer. biol. hum. Dipl.-Ing. (FH) Bogna Stawarczyk, MSc

Department of Prosthodontics, Dental School, Ludwig-Maximilians-University Munich, Goethestrasse 70, 80336 Munich, GERMANY

Tel.: +49 89 4400 59573

Fax: +49 89 4400 59502

Email: [bogna.stawarczyk@med.uni-muenchen.de](mailto:bogna.stawarczyk@med.uni-muenchen.de)

## ABSTRACT

**Purpose:** This study investigates the retention loads of differently fabricated secondary telescopic polyetheretherketone crowns on cobalt-chromium primary crowns with different tapers. **Material and Methods:** Cobalt-chromium primary crowns with 0°, 1° and 2° tapers were constructed, milled and sintered. Corresponding secondary crowns were fabricated by milling, pressing from pellets and pressing from granules. For these 9 test groups, the pull-off tests of each crown combination were performed 20 times and the retention loads were measured (Zwick 1445, 50 mm/min). Data were analyzed using linear regression, co-variance analysis, mixed models, Kruskal-Wallis and Mann-Whitney-U test together with the Benferroni-Holm correction. **Results:** The mixed models co-variance analysis reinforced stable retention load values ( $p=0.162$ ) for each single test sequence. There was no interaction between the groups and the separation cycles ( $p=0.179$ ). Milled secondary crowns with 0° showed the lowest mean retention load values compared to all tested groups ( $p=0.003$ ) followed by those pressed from pellets with 1°. Regarding the different tapers, no effect of manufacturing method on the results was observed within 1° and 2° groups ( $p=0.540$  and  $p=0.052$ ). However, among the 0° groups, the milled ones showed significantly the lowest retention load values ( $p=0.002$ ). Among the manufacturing method both pressed groups showed no impact of taper on the retention load values ( $p>0.324$  and  $p>0.123$ , respectively) whereas among the milled secondary crowns, the 0° taper showed significantly lower retention load values than the 1° and 2° taper ( $p<0.002$ ).

**Conclusion:** Based on these results, telescopic crowns made of polyetheretherketone seem to show stable retention load values for each test sequence. However, data with thermo-mechanical aging are still required. In addition, further developments in CAD/CAM manufacturing of polyetheretherketone materials for telescopic crowns are warranted, especially for 0°.

**Keywords:** cobalt chrome molybdenum alloy, telescopic crown, conus crown

## INTRODUCTION

Alloys for prosthodontic restorations have developed in types and numbers over the past few decades<sup>1</sup>. Especially cobalt-chromium (CoCr) alloys, generally used as medical devices<sup>2</sup>, were often described in applied prosthodontic restorations.<sup>3,4</sup>

Many of these studies mentioned a high corrosion resistance of CoCr alloys considering that the material is suitable as an alternative for fixed dental prostheses (FDPs).<sup>5</sup> The latter have high shown survival rates with few complications and biocompatibility over 3 to 7 years with excellent fit of the crown.<sup>6,7</sup>

This explains the use of CoCr alloy for even highly precise primary and secondary crowns<sup>8</sup> which are used to fix removal dental prostheses (RDPs) on the residual dentition. Thereby, the primary crown is cemented on the tooth, whereas the secondary crown is integrated in the dental prosthesis<sup>9</sup> which enables the patients to remove their dental prosthesis. The retention loads, created by adhesion and wedging, between the primary and secondary crowns allow temporary bond in the patient's mouth.<sup>10,11,12</sup> Clinically, no relevant change of retention loads could be experienced over a period of 1.5 years. Hence, the system seems sufficient for denture retention.<sup>13</sup>

RPDs have established themselves for more than 20 years with clinical success.<sup>13</sup> Behr and co-workers<sup>12</sup> determined only the cementation of the primary crown as weak point of double crown RPDs, which can easily be handled. Güngör and co-workers<sup>14</sup> assessed the correlation between taper angles of 2°, 4° and 6° combined with 3 abutment heights of 4, 5 and 6 millimeters. As a result, the increase of height showed an increase of the retention load. In contrast, the increase of taper angle showed a decrease of the retention load.<sup>14</sup> Compared to titanium and gold alloys, CoCr alloys showed no disadvantage concerning the retention load when used in the long-term.<sup>3</sup>

In order to modernize and simplify the manufacturing process chalky blanks made out of a CoCr alloy were developed. Recently, the result of tested fracture loads of FDPs, which

were produced in a CAD/CAM milling process, showed no significant differences in contrast to conventionally cast FDPs.<sup>15</sup>

In addition, new materials based on polyetheretherketone (PEEK) were introduced to the market and has been marketed as potential alternative material<sup>16</sup> for surgical procedures such as interbody fusion cages<sup>17</sup> or dental implants<sup>16</sup>, which had a similar stress distribution as titanium implants.<sup>18</sup> Being an inert material, PEEK convinced with its high biocompatibility and showed a successful clinical history in spinal implants over more than a decade and a half.<sup>19</sup>

Considering the fact that there are existing procedures to connect PEEK with other resin materials, i.e. veneering and luting, it nowadays also became a suitable material for dental applications, e.g. FDPs or other restorative materials. The usage of PEEK for RDPs has already been examined in combination with clasps and showed sufficient retention values for clinical applications.<sup>20</sup>

Three manufacturing methods of PEEK are known so far: i. milling (PM), ii. pressing from pellets (PPP) and iii. pressing from granules (PPG). Examining the fracture loads of FDP's made of PEEK with these three manufacturing methods, they have proven to be resistant and have met clinical demands.<sup>21</sup> Because the information regarding telescopic crowns is still scarce, this study aimed at investigate the retention load of differently fabricated telescopic PEEK crowns and to elaborate out the interaction of i. new and proved materials (PEEK vs. CoCr), ii. new manufacturing methods of new materials (PEEK milled vs. PEEK pressed) and iii. new manufacturing methods of traditional materials (CoCr milled vs. CoCr cast). This study is about establishing the impact of number of separation cycles, the influence of manufacturing method and the taper angle on the retention load.

## **MATERIAL AND METHODS**

All materials used are presented in Table 1. All primary crowns were designed with three types of taper angles, i.e.  $0^\circ$ ,  $1^\circ$  and  $2^\circ$ , respectively. Each taper group consisted of 10 primary crowns. Every production step was performed according to the manufacturer's instruction and monitored by one qualified operator.

### Production of primary crowns

A first molar was used to fabricate 30 metal alloy abutments in order to achieve confident pull-off values. 30 molar tooth abutments made of cobalt-chrome-molybdenum alloy (Remanium GM 800+; Dentauro GmbH & Co KG, LOT 936; Ispringen, Germany, young's modulus 230 GPa) were produced by casting (Globucast; Krupp AG, Essen, Germany) with the lost wax technique.

Each of these similar fabricated abutments was scanned (Ceramill map 300; AmannGirrbach AG, Koblach, Austria, Arti Spray; Dr. Jean Bausch GmbH & Co. KG, Cologne, Germany LOT 110) and converted in a CAD software (Ceramill Mind 2.3.0; AmannGirrbach AG, Koblach, Austria). Based on this, three different data records for primary crowns were created:

1. parallel telescope with chamfer,  $0^\circ$
2. tangential ending cone,  $1^\circ$
3. tangential ending cone,  $2^\circ$

Then, 10 primary crowns of each configuration were milled with Ceramill Motion 2 (AmannGirrbach AG, Koblach, Austria) and the appropriate milling tool (Ceramill Roto Motion 0.6; 1.0; 2.5; AmannGirrbach AG, Koblach, Austria, 0.6 LOT 20120315, 1.0 LOT 20120605, 2.5 LOT 2010605) from a cobalt-chrome-molybdenum alloy (Ceramill Sintron 71 16 millimeter; AmannGirrbach AG, Koblach, Austria LOT 1303045). The sintering process

was made according to the manufacturer's instruction (argon: 1 bar, compressed air: 1.2 bar; Ceramill Argotherm; AmannGirrbach AG, Koblach, Austria).

Subsequently, the sintered primary crowns were air-abraded at the inner surface (10 seconds, 2 bar, 45° angle; basic Quattro IS; Renfert GmbH, Korox 110; Bego GmbH & Co KG, Bremen, Germany, LOT 14878430513). They were bonded to the abutment by a self-adhesive resin cement (Rely X Unicem 2; 3M ESPE AG, Neuss, Germany, LOT 509981) according to supplier's instruction.

The primary crowns bonded on their abutments were then set parallel in the milling and pull-off base made of gypsum (Hera Octastone CN; Heraeus Holding, GmbH, Hanau, Germany, LOT 3252822). The defined insertion direction was achieved with a highly precise electric, water cooled, high-speed hand-held device (W&H Perfecta 900, W&H, GmbH, Bürmoos, Austria) fixed in a parallelometer (F4 basic, SN 40024231, DeguDent, GmbH, Hanau, Germany). The polishing of the primary crowns occurred under standardized conditions (Abraso-Starglanz asg; bredent, Senden, Germany, REF: 52000163). This resulted in 30 highly precise milled and high-gloss polished primary crowns, 10 with an angle of 0°, 10 with an angle of 1° and 10 with an angle of 2°. (Figure 1, 2, and 3)

### Production of secondary crowns

90 secondary crowns were produced with 3 different manufacturing methods and 3 different taper angles (N=10 per group). After each test series, the primary crowns were examined with a microscope (Stemi DV4 SPOT enlargement of 1.6, Carl Zeiss, AG, Oberkochen, Germany) and polished to its original position. To create the files for the secondary crowns, the polished primary crowns were scanned.

i. (PM): The first test series was based on a milling process. The used parameters for secondary crowns were optimized for the PEEK material (breCAM.BioHPP Blank; bredent



GmbH & Co.KG, Senden, Germany, LOT 394172) to avoid handmade post-processing (additional distance occlusal: 0,5mm; virtual widening X/Y: 0,03 mm, no spacer for cementation, no block out) (Figure 4). The data records for the secondary crowns included a kind of roof ridge used as a link for the extractor device. With these data records the secondary crowns were milled (Zenotec 4030m1; Wieland+Dental GmbH, Pforzheim, Germany).

Having gloss-polished the secondary crowns at the inner surface under standardized conditions, the pull-off tests were started. For this purpose the abutments with primary crowns on their gypsum bases were fixed on the extractor device (Zwick 1445, Zwick GmbH & Co KG, Ulm, Germany) in parallel direction (Figure 7). In combination with the used hook, it made sure to have a good self-centering. With a weight of 5 kg loaded on top for 20 sec, each secondary crown was placed on its primary crown. The artificial saliva used imitated clinical conditions (Glandosane, cell pharm, GmbH, Bad Vilbel, Germany, No 9235461109). The extractor device of the universal testing machine worked with 50 mm per min and with a minor load of: 0.1 N. 20 pull-off tests of each secondary crown were executed. Basis for the statistics were the achieved maximum values of the retention load.

The pressing process for the secondary crowns of the second and third test series was executed with a lost wax method. Again, the data records were used to mill 60 secondary crowns made of wax (brecam.wax 98x20; bredent GmbH & Co KG, Senden, Germany LOT 382697, Zenotec 4030m1; Wieland+Dental GmbH, Pforzheim, Germany).

ii. (PPP): 30 wax crowns were used for PEEK in pellet form (pre-formed cylindrical shape, Figure 5). 6 wax crowns were positioned in one mold (for 2 press, Mold set (metal ring), 26 mm; bredent GmbH & Co KG, Senden, Germany, Ref 360F2P20) and were enclosed with investment material. According to supplier's instruction, the investment material was mixed (420 g investment material (Brevest for 2 press; bredent GmbH & Co KG, Senden, Germany, LOT 1), 58 ml liquid (Bresol for 2 press; bredent GmbH & Co KG,

Senden, Germany, LOT 1), 48 ml distilled water), cured for 20 min and preheated with the pellets (BioHPP, substructure material for permanent, fixed and removable dental restorations; bredent GmbH & Co KG, Senden, Germany, LOT 393554) and the piston (for 2 press filler, 26 mm; bredent GmbH & Co KG, Senden, Germany, LOT 397014). The pressing machine (for 2 press; bredent GmbH & Co KG, Senden, Germany,) executed the pressing process by lowering the piston (4.5 bar, 230 sec) and keeping the pressure for 35 min. The manufactured working pieces were divested manually, cleaned by air-abrading (abrasive-blasting corundum, aluminium oxide 50my; Orbis dental Handels GmbH, Münster, Germany, LOT 20122617) and polished under standardized conditions. The pull-off tests were performed as described before.

iii. (PPG): The third test series, made of granulated raw material, had a similar production process as the production of PEEK pellet (Figure 6). Again 30 secondary crowns made of wax were processed. The diameter of the feeding cylinder (for 2 press, Mold set (metal ring), 20 millimeter; bredent GmbH & Co KG, Senden, Germany, Ref 360F2P20) and the piston (for 2 press filler, 20 mm; bredent GmbH & Co KG, Senden, Germany, LOT 397014) were adjusted to the granules (BioHPP, crown and bridge substructure material; bredent, Senden, Germany, LOT 386694). The granules were pressed with the similar heating and cooling process and the common procedure for the investment material, executed with the common pull-off test.

### Statistical analyses

A linear regression was applied to disclose the association of separation cycles and retention loads for each test group separately. In addition, a co-variance analysis and a mixed models co-variance analysis were provided to investigate the stability of the separation cycles between the test groups. Verification of data normality was accomplished using Kolmogorov-Smirnov and Shapiro-Wilk tests.

Minimum, median, maximum and interquartile values were calculated for each test group separately. The non-parametric Kruskal-Wallis test was applied to disclose differences in mean retention load between the nine test groups. The Mann-Whitney-U test, together with the Benferroni-Holm correction, was used as a post-hoc test. All statistical analyses were done with IBM SPSS (Version 22; IBM Corporation) and the significance level of  $p < 0.05$ .

A post-hoc power analysis for the impact of manufacturing processes of PEEK secondary crowns on retention load was performed. A sample size of 10 in each group had 84% power to detect a difference in retention load means of 10 N (according to the observed data for taper angle  $0^\circ$ ) assuming that the common standard deviation of retention load is 6 N using a two group t-test with a Bonferroni corrected two-sided significance level equal 0.016.

To find differences between the tested taper angles, a sample size of 10 in each group has 83% power to detect a difference in retention load means of 9 N (according to the observed data for PM) assuming that the common standard deviation of retention load is 5.5 using a two group paired t-test with a Bonferroni corrected two-sided significance level equal 0.016.

## RESULTS

The results of the co-variance analysis discloses that, in global, there is no influence of the separation cycles on retention load ( $p=0.184$ ). Considering the linear regression, only in the PPG group with  $0^\circ$  ( $p=0.014$ ), the retention load values increased with the number of the separation cycles (Table 2). Moreover, the mixed models co-variance analysis, correcting for each specimen, reinforced that the retention load is stable with separation cycles ( $p=0.162$ ). There was no interaction between the groups and the separation cycles ( $p=0.179$ ).

The normal distribution tests, i.e. the Kolmogorov-Smirnov and Shapiro-Wilk tests, indicated no violation of the assumption of normality for 88.9% of the tested groups. Only 11.1% were

not normally distributed (1 group out of 9). The robust descriptive statistics for mean retention load are shown in Table 2 and Figure 8.

In general, the non-parametric Kruskal-Wallis test showed significant differences between the nine test groups ( $p < 0.001$ ). PM with  $0^\circ$  showed lower mean retention load values compared to all tested groups ( $p < 0.003$ ) with exception of PPP with  $1^\circ$ . In addition, PPP with  $1^\circ$  performed lower mean retention load values than PM with  $2^\circ$  and PPG with  $0^\circ$  ( $p < 0.003$ ).

Regarding the taper, no effect of manufacturing method on the results was observed in the  $1^\circ$  and  $2^\circ$  group ( $p > 0.540$  and  $p > 0.052$ ), respectively. However, among the  $0^\circ$  taper, the milled crowns showed significantly lower retention loads than compared to the other groups ( $p < 0.002$ ). Regarding the manufacturing method, the PPP and PPG groups showed no impact of taper angle on the retention load values ( $p > 0.324$  and  $p > 0.123$ , respectively). However, within the PM group, the  $0^\circ$  taper showed significantly lower retention load values than the  $1^\circ$  and  $2^\circ$  taper ( $p < 0.002$ ).

## DISCUSSION

In this study, CAD/CAM milled and sintered CoCr primary crowns with 0°, 1° and 2° tapers were constructed and assembled to corresponding secondary crowns made of Polyetheretherketone (PEEK). The investigation showed overall significant results related to separation cycles, taper angles and manufacturing methods.

So far, the retention load values of all groups were stable during the separation cycles, and the PPG group of 0° showed an increase of retention load during the 20 separation cycles. Due to its industrial pre-pressing, which improved mechanical properties<sup>21</sup>, PEEK milled and pressed from pellets (both industrial pre-pressed) have already shown a higher fracture load in contrast to PEEK pressed from granules. It is assumed that the missing industrial prepressing of the secondary crowns made of granules also had an influence on the retention load values. This especially pertains to the 0° group, because of the manufacturing difficulties of 0°.<sup>22</sup>

Concerning the manufacturing method, the manufacturing process and the precision of the milling process may have caused lower retention load values of the milled crowns of 0° in this study. The nature of the milling path, depending on the work piece, the used material and the milling strategy have to be seen as a limitation of the CAD/CAM fabricated secondary crowns in this study because of their influence on quality of the inner surface of the secondary crown, which is important for the retention load.<sup>23</sup> Due to the air-abrading process of the pressed secondary crowns, the inner surface is different compared to the milled inner surface, which also affects the retention load values.

Within the groups of 1° and 2°, the manufacturing method showed no significant impact. Beuer and co-workers<sup>22</sup> mentioned that the double-crown design influenced the retention load. The chamfer is unavoidable for building up adhesion; however, it limits the final apical position.<sup>22</sup> It can be assumed that - due to the material properties of PEEK - the impact of the double-crown design itself (chamfer design 0° vs. tangential ending of 1° and 2°) exceeds the influence of the manufacturing method.

Though there was no impact of taper angle in the PPG and PPP groups, the PM group was influenced by the taper angle. As mentioned above, the lower retention loads of  $0^\circ$  may be a result of manufacturing methods.<sup>22</sup>

Prior studies showed the decrease of retention load with increasing taper with the spread of  $6^\circ$ .<sup>14</sup> As Dillschneider and co-workers<sup>24</sup> have already mentioned, the range of  $2^\circ$  seems to be insufficient to confirm former statistical relationships of taper and retention loads even for the PEEK material. However, the taper of maximum  $2^\circ$  considered in this study, is recommended for long-term usage.<sup>25</sup>

Due to the missing standardized procedures and protocols when investigating and assessing double crown systems, the experimental set-up for pull-off tests in this study tried to correspond to former investigations as good as. Having positioned the secondary crowns parallel in the testing machine, the pull-off direction of the testing machine was perpendicular. The jig, together with the hook and the parallel setting of the secondary crowns made sure to have a good self centering and avoided wedging during the pull off tests. The recommended preload of 50 N was used, due to the fact that the retention loads do not change with a higher preload of more than 50 N<sup>25</sup>. The used pull-off speed of 50 mm/min tried to compromise the values of known clinical tests with realizable technical settings.

PEEK's advantages, being free-of metal, inert and biocompatible, softer regarding its processing capabilities, are highly promising, further developments in CAD/CAM manufacturing are justifiable, especially for  $0^\circ$ .

Despite the fact that artificial saliva tried to simulate the humidity of oral conditions, some limitations of this study concerning the oral environment must also be taken into consideration. Cyclic fatigue loading can significantly weaken the retention load of telescopic crowns. In addition, no thermo-mechanical loading was simulated. These are shortcomings of the current investigation.

Further investigations regarding fatigue testing and thermo-mechanical loading will be beneficial to recognize long term trends. Clinical studies are finally required to support the use of PEEK for telescopic crowns in long-term evaluations.

## **CONCLUSIONS**

Based on this study, telescopic crowns made of polyetheretherketone seem to show stable retention load values for each test sequence. However, data with thermo-mechanical aging are still required. In addition, further developments in CAD/CAM manufacturing of polyetheretherketone materials for telescopic crowns are justifiable, especially for 0°.

## **ACKNOWLEDGMENTS**

The authors would like to thank bredent for providing the materials and financial support of this study. Ceramill Sintron blank were provided from AmannGirrbach. We are grateful to Dirk Nüchel from Dental Softworks for the support in software problems.

## REFERENCES

1. Wataha JC: Alloys for prosthodontic restorations. *J Prosthet Dent* 2002;87:351-363
2. Conti MC, Karl A, Wismayer PS, et al: Biocompatibility and characterization of a Kolsterised® medical grade cobalt-chromium-molybdenum alloy. *Biomater* 2014;4:1-10.doi 10.4161/biom.27713
3. Besimo Ch, Graber G, Flüher M: Retention force changes in implant-supported titanium telescope crowns over long-term use in vitro. *J Oral Rehabil* 1996;23:372-378
4. Sakai Y, Takahashi H, Iwasaki N, et al: Effect of surface roughness and tapered angel of cone crown telescopic system on retention force. *Dent Mater J* 2011;30:635-641
5. Viennot S, Dalard F, Lissac M, et al: Corrosion resistance of cobalt-chromium and palladium-silver alloys used in fixed prosthetic restorations. *Eur J Oral Sci* 2005;113:90-95
6. Svanborg P, Långström L, Lundh RM, et al: A 5-year restrospective study of cobalt-chromium-based fixed dental prostheses. *Int J Prosthodont* 2013;26:343-349
7. Eliasson A, Arnelund CF, Johansson A: A clinical evaluation of cobalt-chromium metal-ceramic fixed partial dentures and crowns: A three- to seven-year retrospective study. *J Prosthet Dent* 2007;98:6-16
8. Ohida M, Yoda K, Nomura N, et al: Evaluation of the static frictional coefficients of Co-Cr and gold alloys for cone crown telescope denture retainer applications. *Dent Mater J* 2010;29:706-712
9. Schwindling FS, Dittmann B, Rammelsberg P: Double-crown-retained removable dental prostheses: a retrospective study of survival and complications. *J Prosthet Dent* 2014;112:488-493



10. Özyemişçi-Cebeci N, Yavuziymaz H: Comparison of the effects of friction varnish and electroforming on the retention of telescopic crowns. *J Prosthet Dent* 2013;109: 392-396
11. Langer A: Tooth-supported telescope restorations. *J Prosthet Dent* 1981;45:515-520
12. Behr M, Hofmann E, Rosentritt M, et al: Technical failure rates of double crown-retained removable partial dentures. *Clin Oral Investig* 2000;4:87-90
13. Bayer S, Stark H, Gözl L, et al: Clinical retention force development of double crowns. *Clin Oral Investig* 2012;16:407-411
14. Güngör MA, Artunç C, Sonugelen M: Parameters affecting retentive force of conus crowns. *J Oral Rehabil* 2004;31:271-277
15. Krug KP, Knauber AW, Nothdurft FP: Fracture behavior of metal-ceramic fixed dental prostheses with frameworks from cast or a newly developed sintered cobalt-chromium alloy. *Clin Oral Investig* 2015;19:401-411
16. Schwitalla A, Müller WD: PEEK dental implants: a review of the literature. *J Oral Implantol* 2013;39:743-749
17. Toth JM, Wang M, Estes BT, et al: Polyetheretherketone as a biomaterial for spinal applications. *Biomaterials* 2006;27:324-334
18. Schwitalla AD, Abou-Emara M, Spintig T, et al: Finite element analysis of the biomechanical effects of PEEK dental implants on the peri-implant bone. *J of Biomech* 2015;48:1-7
19. Kurtz S, Devine J: PEEK biomaterials in trauma, orthopedic, and spinal implants. *Biomater* 2007;28:4845-4869
20. Tannous F, Steiner M, Shahin R, et al: Retentive forces and fatigue resistance of thermoplastic resin clasps. *Dent Mater* 2012;28:273-278

21. Stawarczyk B, Eichberger M, Uhrenbacher J, et al: Three-unit reinforced polyetheretherketone composite FDPs: Influence of fabrication method on load-bearing capacity and failure types. Dent Mater J 2015;34:7-12
22. Beuer F, Edelhoff D, Gernet W, et al: Parameters affecting retentive force of electroformed double-crown systems. Clin Oral Invest 2010;14:129-135
23. Becker H: Der Einfluss von Zahnpasta auf das Haftverhalten parallelwandiger Teleskopkronen Zahnärztliche Praxis 1983;8:332
24. Dillschneider T, Nothdurft FP, Abed-Rabbo M, et al: In vitro-investigations on the wear behavior of different double crown systems. Dent Mater 2009;25:e20
25. Ohkawa S, Okane H, Nagasawa T, et al: Changes in retention of various telescope crown assemblies over long-term use. J Prosthet Dent 1990;64:153-158

## LEGENDS

Figure 1: Primary crown with 0° on its abutment tooth.

Figure 2: Primary crown with 1° on its abutment tooth.

Figure 3: Primary crown with 2° on its abutment tooth.

Figure 4: Polyetheretherketone blank for the milling process (PM).

Figure 5: Polyetheretherketone in pellet form for the casting process (PPP).

Figure 6: Polyetheretherketone granules for the casting process (PPG).

Figure 7: Secondary crown with a hook on its primary crown during the pull-off tests.

Figure 8: The boxplot graph shows the distribution of all retention load measurements.

## TABLES

Table 1: Summary of products used.

Table 2: Robust descriptive statistics of mean retention load including minimum (Min), median (Med), maximum (Max) and interquartile range (IQR) together with the result from linear regression.

## FIGURES

Figure 1: Primary crown with 0° on its abutment tooth.

Figure 2: Primary crown with 1° on its abutment tooth.

Figure 3: Primary crown with 2° on its abutment tooth.

Figure 4: Polyetheretherketone blank for the milling process (PM).

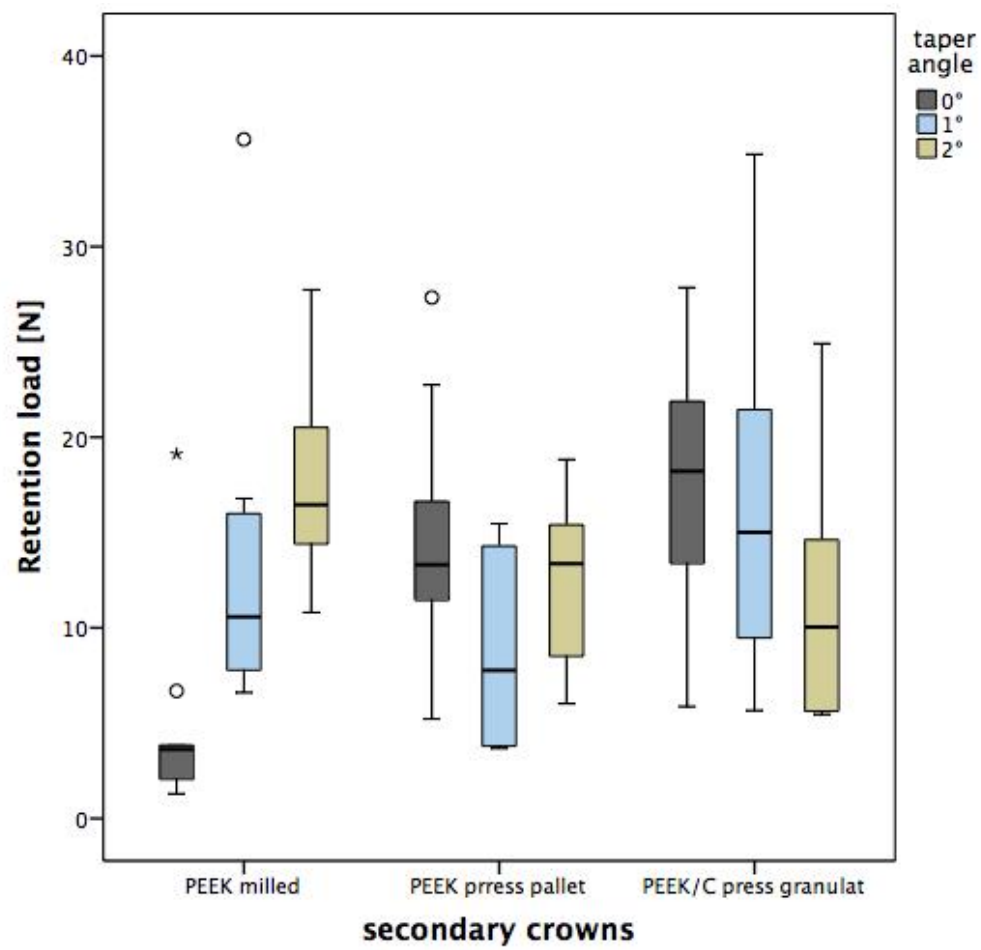
Figure 5: Polyetheretherketone in pellet form for the casting process (PPP).



Figure 6: Polyetheretherketone granules for the casting process (PPG).

Figure 7: Secondary crown with a hook on its primary crown during the pull-off tests.

Figure 8: The boxplot graph shows the distribution of all retention load measurements.



## TABLES

Table 1: Summary of products used.

		material	abbreviation	manufacturer
Primary crowns	milled	Ceramill Sintron 71 Blank 16 millimeter LOT 1303045		AmannGirrbach AG
Secondary crowns	milled	breCAM.BioHPP Blank LOT 394172	PM	bredent GmbH & Co KG
	PEEK pellet	BioHPP, substructure material for permanent, fixed and removable dental restorations 15 grams Pellets LOT 393554	PPP	
	PEEK granular	BioHPP, crown and bridge substructure material 100 grams Granulat LOT 386694	PPG	
Milling process	Machine	Zenotec 4030ml		Wieland i-mes GmbH
Manufacturing PEEK pellet	Wax	brecam.wax 98x20 LOT 382697		bredent GmbH & Co KG
	Investment Material	Brevest for 2 press LOT 1		
	Liquid	Bresol for 2 press LOT 1		
	Press furnace	for 2 press unit		
Manufacturing PEEK granular	Wax	brecam.wax 98x20 LOT 382697		
	Investment Material	Brevest for 2 press LOT 1		
	Liquid	Bresol for 2 press LOT 1		
	Press furnace	for 2 press unit		

Table 2: Robust descriptive statistics of mean retention load including minimum (Min), median (Med), maximum (Max) and interquartile range (IQR) together with the result from linear regression.

Test groups	Minimum	Median	Maximum	IQR	slope	p-value
Parallel 0°						
PM	1.3	3.6a/A	19.1	2.5	-0.005	0.932
PPP	5.2	13.3a/B	27.3	7.3	-0.034	0.673
PPG	5.9	17.7a/B	24.5	8.2	0.175	0.014
Core 1°						
PM	6.6	10.6b/A	35.6	8.6	0.185	0.075
PPP	3.7	7.7a/A	16.2	5.9	0.053	0.331
PPG	5.7	15.5a/A	34.8	12.7	-0.037	0.735
Core 2°						
PM	10.8	16.5b/A	27.7	6.8	0.054	0.421
PPP	6.0	13.4a/A	18.8	7.9	-0.025	0.675
PPG	5.5	10.0a/A	24.9	11.0	-0.049	0.578

a,b: differences between the parallel and cone crowns within one manufacturing method, separately

A,B: differences between the material group within parallel and cone crowns, separately